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THESIS

OPTIMIZING PROCUREMENT OF SPECIAL OPERATIONS WEAPONS AND EQUIPMENT

by

Michael A. Pfarrer

June 2000

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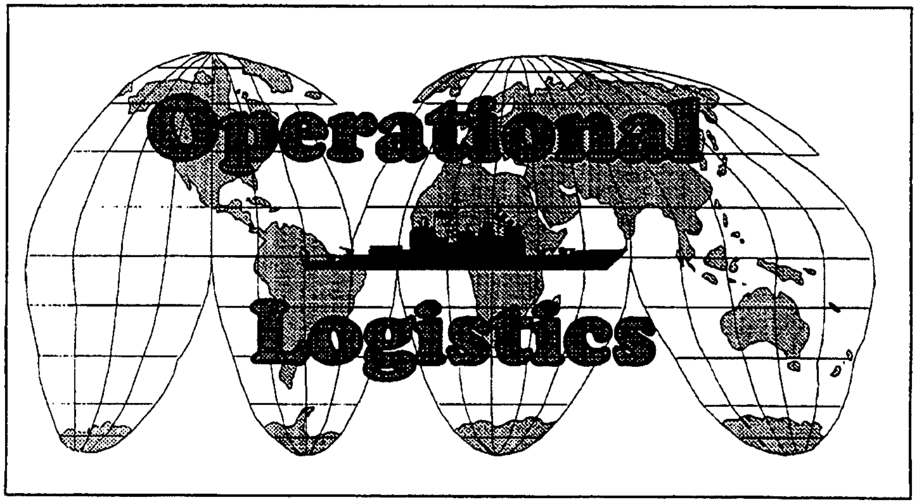
Professionals study logistics



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The Joint Operational Stock (JOS) is a centrally-located inventory of Special-Operations-peculiar weapons and equipment, managed by the United States Special Operations Command (USSOCOM). New procurement of JOS weapons and equipment is currently planned by manually prioritizing the item-wise shortfalls experienced in the JOS inventory during the previous year. This method has not always provided convincing justification for funding, as indicated by the loss of such funding in fiscal year 1999. Also, new technology and other items not historically demanded must be handled in an ad-hoc fashion. We introduce a procurement planning tool that seeks to maximize the ability to completely loadout special operations missions by coordinating year-by-year procurement of individual items. Rather than focus just on history, we concentrate on supporting future missions over an entire multi-year planning horizon. The plans are quickly suggested by a simple greedy myopic heuristic that we show to produce almost-optimal advice.

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OPTIMIZING PROCUREMENT OF SPECIAL OPERATIONS WEAPONS AND EQUIPMENT

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Submitted in partial fulfillment of the
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ABSTRACT

The Joint Operational Stock (JOS) is a centrally-located inventory of Special-Operations-peculiar weapons and equipment, managed by the United States Special Operations Command (USSOCOM). New procurement of JOS weapons and equipment is currently planned by manually prioritizing the item-wise shortfalls experienced in the JOS inventory during the previous year. This method has not always provided convincing justification for funding, as indicated by the loss of such funding in fiscal year 1999. Also, new technology and other items not historically demanded must be handled in an ad-hoc fashion. We introduce a procurement planning tool that seeks to maximize the ability to completely loadout special operations missions by coordinating year-by-year procurement of individual items. Rather than focus just on history, we concentrate on supporting future missions over an entire multi-year planning horizon. The plans are quickly suggested by a simple greedy myopic heuristic that we show to produce almost-optimal advice.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification and validation is at the risk of the user.

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LIST OF TERMS AND ACRONYMS

TERMS:

Heuristic	Optimizing method that suggests good solutions, but cannot assess whether even better solutions exist.
Loadout	All the equipment required by a SOF team to complete a mission.
Loadout Ratio	The ratio between the number of items issued and the number requested.
Mission Ability	Ability to completely loadout a mission during a given period.
Mission Ability Years	The total number of missions completely loaded out in a given year.
SOF Team	A squad of Special Operations trained personnel containing between eight and twelve members.

ACRONYMS:

DA	Direct Action (DA1 is Direct Action mission 1)
FY	Fiscal Year
GAMS	General Algebraic Modeling System
JOS	Joint Operational Stock
O&M	Operational and Maintenance Budget
SO	Special Operations
SOF	Special Operations Forces
SR	Special Reconnaissance (SR1 is Special Reconnaissance mission 1)
USSOCOM	US Special Operations Command

EXECUTIVE SUMMARY

Special Operations Forces (SOF) serve a vital role in preserving the national security of the United States and its allies. SOF units may conduct operations anywhere, with the missions ranging in size and objective, and units called on to perform anything from sabotage of an enemy's communication network to providing humanitarian assistance to hurricane victims. In order to perform these unconventional missions, SOF units require a variety of Special Operations (SO)-peculiar weapons and equipment.

The United States Special Operations Command (USSOCOM) has devised the Joint Operational Stock (JOS) inventory to meet the distinctive demands for SO-peculiar equipment. The majority of the initial JOS inventory was collected following Operation Desert Storm. Since then, JOS has grown to accommodate the evolving requirements of the SO-community and new technology.

JOS is managed by USSOCOM and is located in Lexington, Kentucky. Equipment from the JOS inventory is loaned to SOF units for operations, and later returned to Lexington when the operations are complete. This revolving inventory saves money because each line item (type of equipment) can be held in central stock in fewer numbers.

JOS is maintained by a yearly budget, which is split into two separately managed component funds. The Procurement Fund is for purchasing additional line items already in JOS, as well as new technology items. The Operational and Maintenance (O&M) Fund is

used for the operation of JOS, including the maintenance, management and repair of the existing JOS inventory.

USSOCOM develops its yearly JOS procurement plan from historical demand and manual calculation of which items increase the projected overall effectiveness of the JOS inventory to fully equip missions. This manual planning is not hard to describe: calculate the historical loadout ratio (the amount issued divided by the amount requested) for each item, find those items with the lowest loadout ratio, and buy them. Although straightforward, this process does not consider synergistic effectiveness among items purchased nor does it consider procurement of new technology equipment or future year planning. The manager somehow decides how much money to use on the procurement of critically-needed items and how much money to set aside for new technology and future requirements.

USSOCOM makes annual budget requests for JOS inventory. In fiscal year 1999, the JOS request was denied. USSOCOM needs to maintain an annual allotment for JOS in order to procure new equipment and overhaul and modernize old or broken equipment. Unless some form of shopping list is annually approved, and actually purchased, shortfalls in JOS will develop and grow along with obsolescence. This will result in the deployment of SOF teams with out-of-date equipment or partial equipment loadouts.

We suggest a new method to plan JOS procurement over an entire multi-year planning horizon. Rather than focus on "what happened" with individual items in the past, we suggest focusing on "what mission capabilities do we need" in the future. That is, we want to synchronously procure items such that we achieve complete mission capability as

soon as possible for as many candidate missions as possible. We want to consider new technology as it becomes available, and will plan for the retirement of old out-of-date equipment when its life cycle expires. Our objective is to maximize the total JOS mission ability (the number of missions that JOS can simultaneously and completely loadout in a given year) every year in the planning horizon.

Most of all, we want to provide a planning tool that is easy to use and understand, and we want to show that the tool works and can be trusted.

We develop a fast, simple heuristic that shows how the purchase of each new item increases ability to support an SO mission. Our myopic heuristic solution technique quickly generates a shopping list for every year in a planning horizon, maximizing the total mission ability of JOS while following the planned annual budget limits.

We construct a ten-year planning scenario with mission loadouts for a variety of candidate missions drawn from surveys of SOF units, and the introduction and retirement of various equipment items throughout the planning horizon.

We test our heuristic solution technique against a mathematical optimization model that is omniscient over the entire planning horizon, and that produces a procurement plan of known quality.

The myopic heuristic and the omniscient optimization solution techniques suggest remarkably similar shopping lists. By the end of the 10-year planning horizon, both the heuristic and optimal solution techniques achieve the ability to perform 33 simultaneous SO-missions. The omniscient optimal solution technique slightly outperforms the myopic

heuristic solution technique in that it achieves a few mission abilities a bit earlier than the heuristic.

If the heuristic solution technique were omniscient, it might produce solutions resembling those of the optimal approach. However, considering the good quality of its plans, the heuristic's myopia is one of its attractions, because when future conditions in the scenario are slightly changed, such as budget, mission types, item service life, etc., the omniscient solution technique can be expected to drastically alter its advice, even if these changes are small and in the distant future. Because the myopic heuristic only plans for the current year, it only takes into account changes made in that year, thus sacrificing some effectiveness, but operating with transparency that is easy to understand.

We conclude that the heuristic solution technique is a simple and easily understood management tool for JOS procurement funding, quickly producing a near-optimal shopping list for every year in a multi-year planning horizon.

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I. INTRODUCTION

A. SPECIAL OPERATIONS FORCE

Special Operations Forces (SOF) are units organized to perform small-scale operations throughout the world that are beyond the capabilities of the regular military, or do not require the mobilization of a large armed force. The United States (US) military is organized to fight and win a major conventional war against any other nation in the world. However, since the conclusion of World War Two, it has repeatedly been small groups or organizations, often not associated with any nation, that have waged war against the United States and its allies. These small conflicts and other operations fall into the realm of special operations. These are the unconventional missions that the SOF units are well suited to perform.

Unconventional warfare as defined by Thomas Adams, Director of Intelligence and Special Operations in the United States Army Peacekeeping Institute, is

> "those military activities conducted within a conflict environment that are not directed toward or directly supporting conventional warfare. It includes humanitarian operations, complex emergencies, insurgency and counterinsurgency, support to civil authority, nation-building and some forms of subversion, sabotage and similar forms of unconventional warfare." (Adams, 1998)

To perform unconventional warfare missions, each service has a special operations group that specializes in the tactics and skills associated with that service. For example, the U.S. Navy Sea Air Land (SEAL) units are experts at anti-ship tactics, while the U.S. Army Special Forces excel in ground combat. The US Special Operations Command

(USSOCOM), established by Congress in 1987, as one of nine unified commands, is organized to provide special operations to "support the geographic commanders-in-chiefs (CINCs), ambassadors and their country teams, and other government agencies." (United States Special Operations Forces Posture Statement, 1996) Under USSOCOM the special operations groups of each of the services are unified to provide a joint force that is able to conduct a broad spectrum of unconventional warfare.

SOF units are a valuable asset for preserving the national security of the United States and its allies. The SOF units are further broken down into teams, which are squads of Special Operations trained personnel containing between eight and twelve members. SOF teams perform a variety of unconventional missions that require a variety of Special Operations (SO)-peculiar weapons and equipment. Depending upon the mission at hand, a SOF team might require anything from a Barrett 50-caliber sniper rifle, to a F-470 Zodiac inflatable boat (see Figure 1).

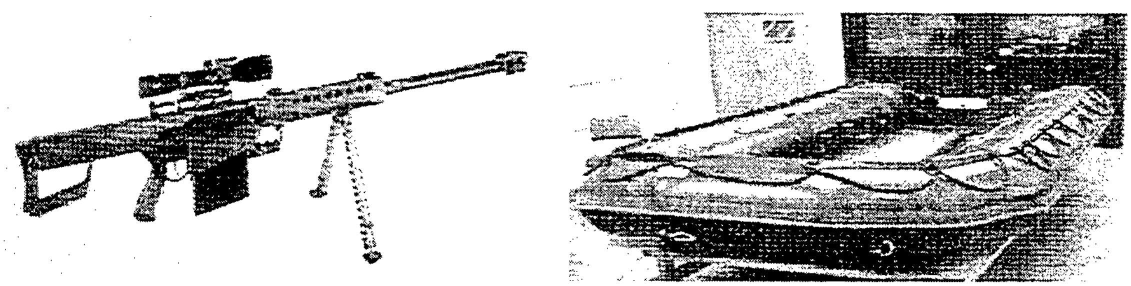

Figure 1. A Barrett 50-caliber sniper rifle and a F-470 Zodiac inflatable boat. Special Operations Forces may be called on to train for and perform a variety of missions. Some missions require specialized weapons and equipment that are loaned from a central storage point to Air Force, Army, and Navy units only when needed. Centrally locating and managing a rotating inventory of about 100 Special Operations-peculiar weapons and equipment reduces the overall cost for supporting Special Operations Forces. Figures are from the Joint Operational Stocks Catalog (SOFSA, 1999).

SOF teams conduct operations throughout the world, with the missions ranging in size and objective; they might be called on to sabotage an enemy's communication network, or to provide humanitarian assistance to hurricane victims. Congressional legislation and joint doctrine dictates the missions for the SOF teams. USSOCOM has outlined these core missions in USSOCOM Publication 1 (USSOCOM PUB 1, 1996), which groups the missions into two categories: principal missions and collateral activities. The principal missions are:

- Direct Action,
- Special Reconnaissance,
- Foreign Internal Defense,
- Unconventional Warfare,
- Combating Terrorism,
- Counter-Proliferation,
- Civil Affairs,
- Psychological Operations, and
- Information Warfare/Command and Control Warfare (USSOCOM PUB 1, 1996).

The collateral activities are:

- Coalition Support,
- Combat Search and Rescue,
- Counter-Drug Activities,
- Counter-Mine Activities,
- Humanitarian Assistance, and
- Security Assistance (USSOCOM PUB 1, 1996).

B. JOINT OPERATIONAL STOCK

USSOCOM has devised the Joint Operational Stock (JOS) inventory to meet the distinctive demands for SO-peculiar weapons and equipment. The majority of the initial JOS inventory was the direct result of Operation Desert Shield and Desert Storm operations conducted in late 1990 and early 1991. In order to meet the demand to outfit SOF teams deploying to the Persian Gulf, USSOCOM was given authorization to purchase a stockpile of SO-peculiar weapons and equipment. When Operation Desert Storm was complete, each of the teams returned the weapons and equipment back to USSOCOM. The original JOS inventory was formed from this stockpile of Desert Storm equipment. Since 1991, JOS has grown in size to accommodate the ever-changing requirements of the Special Operations community and the advent of new technology.

JOS is now a centrally-located inventory of SO-peculiar items that issue SOF team *loadouts* that are used in training or real-world operations, and then returned to stock upon completion of activities. A loadout consist of all the weapons and equipment required to successfully perform an SO-mission. This revolving inventory decreases the annual budget for new acquisitions, maintenance, and storage, because each line item (type of equipment) can be held in central stock in fewer numbers. JOS is located in Lexington, Kentucky, and is managed by the Special Operations Forces Support Activity (SOFSA), a government-owned, contractor-operated facility (see Figure 2).

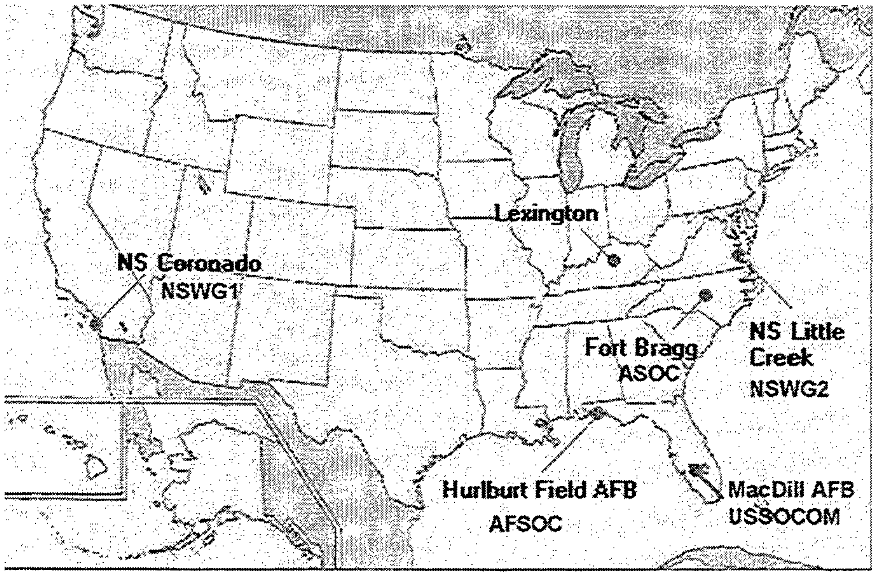

Figure 2. The Joint Operational Stock of Special Operations-peculiar items is located at Lexington, Kentucky. By managing a centrally located inventory of all Special Operations equipment and weapons, the annual cost of new acquisitions, maintenance, and storage is reduced.

JOS is maintained with a yearly budget. This budget is split into two separately managed components. The Procurement Fund is for purchasing additional line items already in JOS, as well as new technology items. The Operational and Maintenance (O&M) Fund is used for the operation of JOS, including the maintenance, management and repair of the existing JOS inventory. The amount of funding allocated to the JOS budget is determined by the approval of USSOCOM's annual JOS budget request. If the request is approved, the entire Procurement Fund as well as a portion of the O&M Funding is allotted toward new JOS item purchases.

The JOS inventory is effective in supplying requested equipment, and has earned high praise from the SOF community. However, due to shortfalls in key areas, JOS is unable to completely fill loadout requests. Retention of equipment and weapons by teams beyond the designated loan periods, an increased SOF Operation Tempo (OPTEMPO),

and pre-existing shortfalls due to lack of funding for acquisition and maintenance, have resulted in the lack of readily available JOS line items. In order to alleviate the JOS inventory shortfalls, the JOS manager must make the best possible use of any JOS funding available.

C. MANAGING PROCUREMENT FUNDS

1. Manual Justification and Management of the JOS Budget

USSOCOM manually justifies its yearly JOS spending by making a list of all of the critically needed items. USSOCOM calculates by hand the loadout ratio for each item requested. The loadout ratio is the historical amount issued or supported, divided by the amount requested. Items that have the smallest loadout ratio are purchased first. The items are incrementally purchased until the annual budget is completely spent. This process is quick and simple, identifying items that have been critically needed. However it does not consider synergistic effectiveness among purchases --- that sets of related items must be available at once for certain missions --- nor does it consider procurement of new technology equipment or future year planning. The manager somehow decides how much money to use on the procurement of critically needed items and how much money to set aside for new technology.

2. Automation of USSOCOM's Manual Method

In a 1999 study, LCDR Phil Fahringer takes USSOCOM's method of justification and management of JOS funding and incorporates it into an automated model (1999). In order to build a model that automatically calculates the loadout ratio for all of the items requested during the preceding period, Fahringer uses a hybrid of Sherbrook's marginal

analysis technique (1992), which is similar to the Navy's aviation inventory model, Aviation Readiness Operation Weapons Systems (ARROWS). Fahringer's model statistically determines the average number of each item requested in the previous period. He determines the best marginal increase --- the loadout ratio achieved when an additional unit of an item is added to the inventory --- among all of the items under review. The model automatically sorts these marginal increases from the largest to smallest. Fahringer's model also incorporates a mission usefulness factor, which gives a relative value to every item in the JOS inventory. Using the sorted list of the marginal increases and taking into account the mission usefulness factors, Fahringer's model produces a shopping list of items that can be purchased within the current year's budget.

Due to a lack of a convincing justification for expenditure of money for JOS, the fiscal year 1999 (FY99) USSOCOM budget did not allocate any funding for JOS, preventing the purchase of items needed to fill the existing shortfalls in the JOS inventory. With the aid of the study completed by Fahringer, USSOCOM was able to restore justification for the expenditure of funds for JOS. As a direct result of this justification, the FY00 budget allocates $500 thousand for the procurement of JOS items for the JOS inventory. (Tisak, 8 September 1999)

The Fahringer model develops a shopping list for only 42 of the 94 JOS line items, due to a lack of historical data. Examples such as PVS-7D Night Vision Goggles (NVG), and the C-141 Hatchmount Satellite Communication (SATCOM) Antenna have no request at all, and certain line items such as the TAC-100 Diver Navigation Board have the number requested equal to the number issued exactly (see Figure 3). Further, the

Fahringer model assumes normality for every item in JOS, which for the majority of items is a reasonable assumption based on the central limit theorem (e.g., Devore, 1995). However, for a few items that were only requested once or twice, this assumption is questionable and grounds for challenging the model's procurement advice.

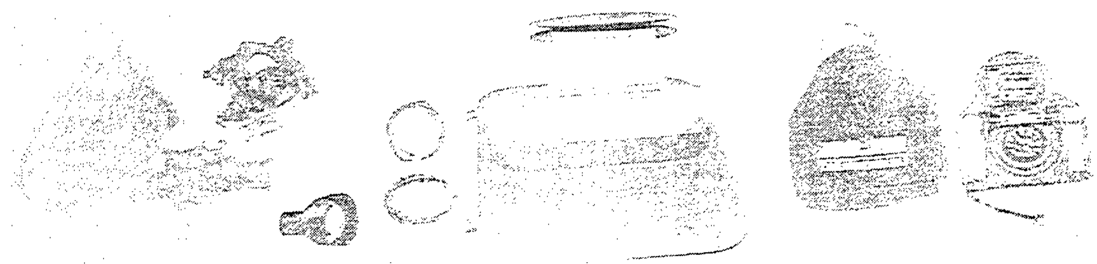

Figure 3. The PVS-7D NVG, C-141 Hatchmount SATCOM Antenna, and TAC-100 Diver Navigation Board (left to right) did not appear on Fahringer's shopping list because of lack of historical data. Fahringer's model only develops a "shopping list" for less than half of the JOS inventory. Figures are from the Joint Operational Stocks Catalog (SOFSA, 1999).

USSOCOM needs to continue to produce an annual "shopping list" in order to justify its expenditure of funds for the JOS inventory. Without a convincing justification for JOS spending, funding for the inventory will be in jeopardy again. USSOCOM needs to maintain an annual allotment for JOS in order to procure new equipment, including high technology gear such as night vision and electro-optics (NVEO) and communications equipment. In addition to purchasing new equipment, old or broken equipment needs to be replaced with up-to-date gear, repaired, or overhauled and modernized. Unless some form of shopping list is approved annually, and actually purchased, the shortfalls in JOS will worsen along with obsolescence. This will result in the deployment of SOF teams with out-of-date equipment or partial equipment loadouts.

II. A NEW METHOD

We suggest a new method to justify JOS funding over an entire multi-year planning horizon. Rather than focus on "what happened" with individual items in the past, we suggest focusing on "what mission capabilities do we need" in the future. That is, we want to synchronously procure items such that we achieve complete mission capability as soon as possible for as many candidate missions as possible. We want to consider new technology as it becomes available, and will plan for the retirement of old out-of-date equipment when its life cycle expires. Our objective is to maximize the total mission ability of JOS every year in the planning horizon. We define total mission ability as the number of missions that JOS can simultaneously and completely load out in a given year. Here we weigh the ability to complete each mission equally, but we can easily accommodate mission priorities.

Most of all, we provide a planning tool that is easy to use and understand, and we prove that the tool works and can be trusted by objectively evaluating the tool with mathematical optimization.

A. MISSIONS

We concentrate on the two dominant principal mission types: Direct Action and Special Reconnaissance missions. These two mission types require the majority of weapons and equipment from the JOS inventory. These mission types are further broken down into specific mission areas. Direct Action (DA) missions are short-duration offensive strikes performed by SOF teams with the objective of seizing, destroying,

capturing, recovering, or inflicting damage on personnel or material, to include the following:

- DA1 - Raids, Ambushes, or Direct Assaults,
- DA2 - Emplacement of mines or other munitions,
- DA3 - Conducting standoff attacks from air, ground, or maritime platforms,
- DA4 - Providing terminal guidance for precision-guided munitions,
- DA5 - Conducting independent sabotage, and
- DA6 - Conducting anti-ship operations (USSOCOM PUB1, 1996).

Special Reconnaissance (SR) missions are surveillance actions conducted by SOF teams in order to obtain information concerning the capabilities, intentions, and activities of a real or potential enemy or to gather data concerning an area of interest, to include:

- SR1 - Target Acquisition,
- SR2 - Area Assessment,
- SR3 - Post-Strike Battle Damage Assessment, and
- SR4 - Collection of Meteorological, Hydrographic, Geographic, and Demographic data (USSOCOM PUB1, 1996).

The six specific DA mission types are defined in the United States Special Operations Forces Posture Statement (1996). A raid, ambush, or direct assault mission is an operation beyond the range of tactical weapon systems or the strike capabilities of conventional forces, which is designed to achieve specific, and time sensitive strategic or operational objectives. The emplacement of mines or other munitions is the offensive use of mines to impede or control the movement or actions of an enemy. Conducting standoff attacks from air, ground, or maritime platforms is when the target can be damaged or

destroyed without the commitment of close-combat forces. The DA mission to provide terminal guidance for precision-guided munitions is to use laser designators or other resources to direct munitions at designated targets from ground positions nearby. Conducting independent sabotage is designed to disrupt, destroy, or neutralize hostile capabilities with a minimum expenditure of manpower and material. Finally, anti-ship operations are actions conducted against enemy shipping, including combatants (see Figure 4).

Figure 4. U.S. Navy SEALs conducting a Direct Action mission. A DA mission is a short-duration offensive strike performed by SOF teams with the objective of seizing, destroying, capturing, recovering, or inflicting damage on personnel or material. JOS is the primary provider for the equipment required to perform this and other SO-missions. Figure is from USSOCOM (Henrickson, 10 March 2000).

The four different SR mission types are also defined in the United States Special Operations Forces Posture Statement (1996). Target acquisition mission is designed to acquire and maintain surveillance of a designated target. Area assessment is when SOF teams deploy to a region to study the culture, political, and other aspects of an area of

interest. Post-Strike Battle Damage Assessment is the gathering of information concerning the results of an air, sea, or land strike. The collection of meteorological, hydrographic, geographic, and demographic data is similar to the area assessment mission, however, it includes the collection of the physical features of the area, including weather, terrain and so forth (see Figure 5).

Figure 5. U.S. Army Special Forces on a Special Reconnaissance Mission. SR missions are surveillance actions conducted by SOF teams in order to obtain information concerning the capabilities, intentions, and activities of a real or potential enemy, or to gather data concerning an area of interest. Like DA missions, JOS provides equipment required to perform a SR mission. Figure is from USSOCOM (Henrickson, 10 March 2000).

In any given year of the planning horizon, a SOF team must be operationally ready to perform any of the various SO-missions. Because these missions often occur concurrently, JOS must be capable of simultaneously supporting each of these missions, or even a multiple of these missions. For instance, JOS must be able to support two DA1s, one of DA2 through DA6, two SR1 and SR2s, and one of SR3 and SR4, simultaneously.

B. TYPICAL MISSION LOADOUTS

The typical SOF team loadout for each of the above DA and SR specific missions is provided by USSOCOM (Henrickson, 21 April 2000) (see Appendix A). Based on responses to a survey of JOS customers and the judgement of a JOS manager, the loadout provided is for a typical mission, and is not designated as the all-encompassing mix of weapons and equipment. We understand that for a real mission, the actual loadout would vary according to operational objectives, area, weather, climate and a multitude of other factors that are beyond the scope of this study. According to USSOCOM, the typical loadout given generally overestimates the actual requirements, thus providing a worst-case scenario (Henrickson, 21 April 2000).

C. JOS FUNDING IN THE PLANNING HORIZON

USSOCOM has provided a projected budget for each year in a ten-year planning horizon (Henrickson, 30 March 2000) (see Table 1). Each year's budget is split into Procurement and O&M funding. In each year of the planning horizon, JOS is allocated the entire Procurement Fund as well as an additional $500 thousand of the O&M Fund.

D. ASSUMPTIONS OF THE NEW METHOD

We have made a few reasonable assumptions. For instance, in order to completely utilize annual budgets, and because each purchase is discrete within a year, we assume that it is reasonable to plan modest over-budget spending to buy a *last* item. However, from year-to-year we keep track of our cumulative spending so that these small over- and under-budget violations are repaid.

Fiscal Year	Procurement Fund (Thousands of Dollars)	O&M Fund (Thousands of Dollars)
FY00	0	2000
FY01	3000	2500
FY02	2000	2500
FY03	2000	2500
FY04	2000	2500
FY05	2000	2500
FY06	2000	2500
FY07	2000	2500
FY08	2000	2500
FY09	2000	2500
FY10	2000	2500

Table 1. Planning Horizon JOS Budget. The funding for JOS is broken up into Procurement and O&M Funds. Each fund provides money for the acquisition of additional existing line items or new technology items for the JOS inventory. The entire Procurement Fund, and $500 thousand of the O&M Fund are dedicated to the yearly purchasing of JOS equipment. (Henrickson, 30 March 2000)

We have also assumed that once a mission ability is achieved, we should continue to maintain it over the remainder of the planning horizon. So, a special "persistence" feature tries to retain a mission ability once it is achieved. It may seem odd, but otherwise we might (and do) see weapons and equipment reallocated to different mission sets over time. While this may be optimal, it is not sensible or face valid, and it is likely a practical consideration that once JOS customers know a mission can be equipped, they will reasonably assume this will persist over time.

These assumptions are optional features, and can trivially be removed if necessary.

IV. THE TOOLS NEEDED TO APPLY THE METHOD

A. THE HEURISTIC

1. Shizuo Senju and Yoshiaki Toyoda Heuristic

Following Senju and Toyoda (1968), we develop a simple heuristic that quickly suggests a frequently near-optimal portfolio of proposals from a large number of candidate proposals, where our choices are restricted by their consumption of a discrete number of limited resources. This heuristic is applicable when an exact solution to an integer linear program is either not necessary or perhaps not possible. The heuristic approximately solves the following R-Knapsack optimization problem:

Indices:

p	candidate proposals ($p = 1, 2, \ldots, P$)
r	limited resources ($r = 1, 2, \ldots, R$)

Data:

$benefit_p$	incremental benefit of proposal p
$available_r$	limit on availability of resource r
$use_{p,r}$	proposal p would use this amount of resource r

Decision Variables:

$ABLE_p$	binary decision ($ABLE_p = 0$ or 1) to select proposal p

Formulation:

$$\underset{ABLE}{\text{Maximize}} \quad \sum_p benefit_p ABLE_p$$

$$\text{Subject to} \quad \sum_p use_{p,r} ABLE_p \le available_r \quad \forall r$$

$$ABLE_p \in \{0,1\} \quad \forall p.$$

We first express the resource r consumption of each candidate proposal p, $use_{p,r}$, as a fraction of resource availability, $available_r$:

$$\widetilde{use}_{p,r} \leftarrow use_{p,r} / available_r \qquad \forall p, r .$$

If any $\widetilde{use}_{p,r}$ is greater than one, proposal p is peremptorily deleted from consideration.

Next, select *all* candidate proposals for our portfolio. Determine which resources would be over-used by this greedy action by finding the consequent $shortfall_r$:

$$\text{for } r = 1, \ldots, R \quad shortfall_r = \max\left\{0,\ \sum_p \widetilde{use}_{p,r} - 1\right\}.$$

If there is no $shortfall_r$ greater than zero, we are finished.

Otherwise, we employ a myopic, greedy, deletion heuristic that determines the selected candidate proposal to delete from the portfolio that yields the smallest reduction in benefit per shortfall reduction.

To determine this, we calculate $criticalresource_p$, which is the estimated fraction of resource shortfalls attributed to selected portfolio proposal p:

$$criticalresource_p = \sum_r \widetilde{use}_{p,r} shortfall_r .$$

We then estimate the benefit lost per critical resource gained by deleting proposal p:

$$sacrifice_p = \frac{benefit_p}{criticalresource_p} = \frac{\text{benefit lost}}{\text{critical resource gained}} .$$

The heuristic deletes the proposal p with the smallest $sacrifice_p$, recomputes the shortfalls, and repeats deletions until a feasible portfolio results.

Once the deletions yield a feasible portfolio of proposals, it is possible that some deleted proposals can be *added* back into the portfolio while retaining feasibility. Thus, a second addition phase exploits any such opportunities.

2. Generalizing to a Myopic Multi-Period Heuristic

We have extended the Senju and Toyoda heuristic for myopic application period-by-period over a multi-period planning horizon.

Each period, any proposal already selected for the portfolio by the prior period is retained. If we seek proposal *persistence*, these retained proposals are never deleted. Otherwise, all candidate proposals are subject to deletion.

Each period, any remaining resources from the prior period are retained, or deleted, as specified by the problem definition. Some resources are persistent, and some are not. Newly-available resources are added to those available for the period.

During each period, the incremental $benefit_p$ of each candidate proposal p may be recomputed as a consequence of successive deletions from, or additions to, the portfolio.

During each period, the deletion, or addition, of a proposal may influence resource availability directly, and indirectly. That is, we may re-compute resource availability for each candidate portfolio as a whole, rather than incrementally update availability as a consequence of each proposal deletion, or addition.

These embellishments are easy to implement. However, because this is, after all, a simple heuristic, their consequences on the quality of the solution are difficult to assess. Suffice to say that as long as the benefit and resource consumptions are *regular* measures of the number of proposals in a portfolio (i.e., the more proposals in the portfolio, the

more benefit, and the more resources consumed), we are heuristically comfortable that reasonable solutions will accrue.

Only true mathematical optimization can tell us for sure whether better solutions exist than those the heuristic finds, and how much better those solutions are. This approach is investigated in Section B.

3. The JOS Heuristic

The JOS problem seeks year-by-year to maximize the number of mission abilities (the benefit of its portfolio) subject to restrictions on budget and the items purchased that are required for mission ability (the limited resources).

Figure 6 illustrates the JOS heuristic. Initial conditions include the mission ability already achieved, the numbers of items in inventory that support this achievement, and any cumulative under- or over-budget spending since the start of the planning horizon. Each mission ability requires a certain loadout of items, and each item may be purchased for a given price. So, the heuristic converts the budget resources into the item resources in order to collect the necessary item loadout to achieve mission ability.

There are some additional details. For instance, the heuristic purchases items and assigns them to a particular mission. This is a restriction of reality, but the intent is clear and the result is much easier to understand and audit.

Some items (weapons and equipment) can be used as substitutes for others, perhaps with replacement multiples other than one-for-one. The JOS heuristic admits substitutions, but purchases preferred items to replace substitutions whenever the substitutions are retired from inventory.

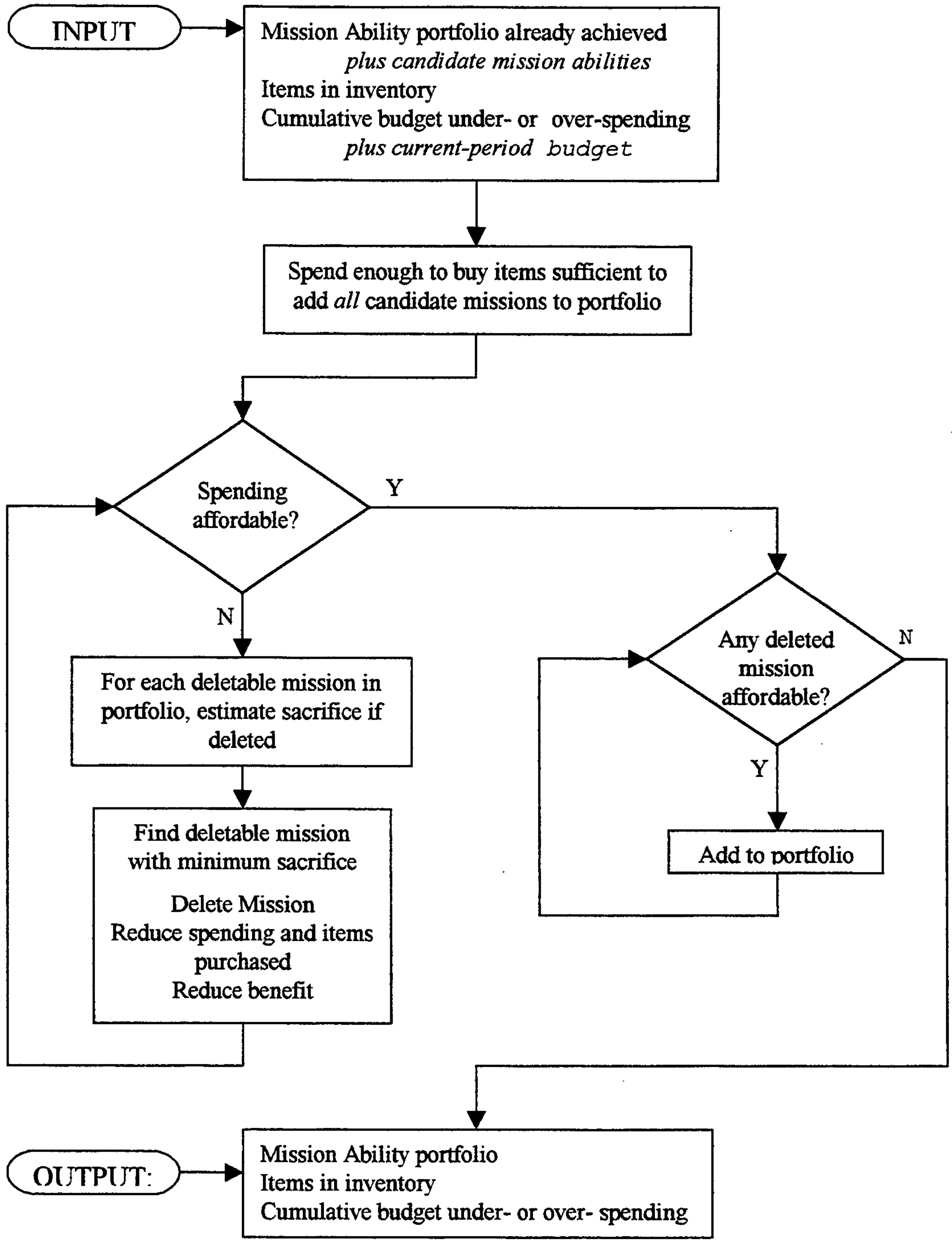

Figure 6. This flowchart shows the salient features of our period-by-period JOS heuristic. If persistent missions ability is required, candidate missions added to the portfolio are never deletable in later periods. If under- or over- budget spending is not allowed, this feature is restricted. Otherwise, penalties that increase with the magnitude of any violation ensure that such violations, if they occur, are justified by their overwhelming benefit.

In any given year, after all candidate missions have been added to a feasible portfolio, there may be some residual budget --- not enough to buy another mission, but enough to buy some items toward another mission. The JOS heuristic selects affordable items that maximize the proportion of mission ability purchased, but not achieved.

Year-by-year, portfolio mission abilities may be retired, new candidate missions may be introduced, new candidate items may be considered, and obsolescent items retired. The heuristic deals with these cases in an obvious way.

The mission benefit is measured in terms of one per mission ability by the end of each year, summed over the planning horizon years. Other mission benefits can be accommodated trivially, as can present value of "fog of future planning" discount rates.

4. The JOS Heuristic Implementation

The heuristic is programmed in EXCEL[tm], though almost any computational language would do, making it compatible with USSOCOM's existing software. The simplicity of the heuristic makes changing it relatively easy.

B. THE OPTIMAL SOLUTION TECHNIQUE

1. Optimal Solution Technique Features

The optimal solution technique is a mixed integer program (MIP) we use as the best solution comparison for the heuristic.

Indices:

i	Joint Operational Stock (JOS) Line Item
ip	All item i's that can be purchased
$is(i)$	Subset of i containing all items that can be substituted for other items
m	Mission Type
$inity$	Initial Planning Year - FY99
y	FY00 thru FY10
$y(i)$	Years in which item i is usable
b	Break Points for Over/Under Budget Violations (5, 10, 15, 20, 25; 30%)

Data:

$missmult_y$	Upper bound on the number of each mission performed each year $\left(mission_m / year_y\right)$
$liuse_{i,m}$	Number of item i required for mission m $\left(item_i / mission_m\right)$
$ssmul_{i,is(i)}$	Number of the substitute item $is(i)$ required to replace i $\left(item_i / item_{is(i)}\right)$
$initstock_i$	Initial Stock of item i at end of FY99 $\left(item_i\right)$
$cost_i$	Cost of item i $\left[(\$/1000)/item_i\right]$
$auth_i$	Authorized number of i allowed to be held in stock $\left(item_i\right)$
$totaluse_i$	Number of item i required to perform all missions $\left(item_i / missions\right)$
$budget_y$	Budget for year y $(\$/1000)$
$break_b$	Percent value at break point $b\,(\%)$

$bdgtpen_{b,over}$ — Over-Budget penalty for break point b $\left[mission\_ability/(\$/1000)\right]$

$bdgtpen_{b,under}$ — Under-Budget penalty for break point b $\left[mission\_ability/(\$/1000)\right]$

$tkpen$ — Persistence penalty $(mission_m\_ability)$

$maxmult$ — Maximum number of mission desired over the planning period

Integer Decision Variables:

$ABLE_{m,y}$ — Binary variable indicating if mission performed during year y $\left(mission\_ability_m / year_y\right)$

$SUBITEM_{i,is(i),y(i)}$ — Number of item $is(i)$ substituted for i in year $y(i)$ $\left(item_{is(i)} / year_{y(i)}\right)$

$STOCK_{i,y}$ — Stock level of item i at end of year y $\left(item_i / year_y\right)$

$NEWBUY_{ip,y}$ — Number of new item ip's purchased in year y $\left(item_{ip} / year_y\right)$

Nonnegative Decision Variables:

$ISSUED_{i,y(i)}$ — Number of item i issued in year $y(i)$ $\left(item_i / year_{y(i)}\right)$

$ADJAUTH_{i,y}$ — Amount the Authorized level needs to be adjusted $\left(item_i / year_y\right)$

$OVERBDGT_{b,y}$ — Amount over the budget for year y by breakpoint b $\left[(\$/1000)/year_y\right]$

$UNDERBDGT_{b,y}$ — Amount under the budget for year y by breakpoint b $\left[(\$/1000)/year_y\right]$

$DNTICK_{m,y}$ — Zero unless mission m ability goes down in year y

$UPTICK_{m,y}$ — Zero unless mission m ability goes up in year y

Formulation:

$$\underset{ABLE}{\text{Maximize}} \sum_{m}\sum_{y} ABLE_{m,y}$$

$$-\left[\sum_{y}\sum_{b} bdgtpen_{b,over} * e^{-0.10*(y-1)} * OVERBDGT_{b,y}\right]$$

$$-\left[\sum_{y}\sum_{b} bdgtpen_{b,under} * e^{-0.10*(y-1)} * UNDERBDGT_{b,y}\right]$$

$$-\left[\sum_{m}\sum_{y} tkpen * e^{-0.10*(y-1)} * DNTICK_{m,y}\right]$$

$$-\left[\sum_{m}\sum_{y} tkpen * e^{-0.10*(y-1)} * UPTICK_{m,y}\right]$$

Subject to:
Mission Loadout Constraints:

$$\sum_{m} liuse_{i,m} * ABLE_{m,y(i)} = ISSUED_{i,y(i)} + \sum_{is(i)} \left(1/ssmul_{is(i)}\right) * SUBITEM_{i,is(i),y(i)} \qquad \forall i, y(i)$$

$$ISSUED_{i,y(i)} + \sum_{is(i)} SUBITEM_{is(i),i,y(i)} \le STOCK_{i,y(i)} \qquad \forall i, y(i)$$

$$STOCK_{i,y-1} + \sum_{ip} NEWBUY_{ip,y} = STOCK_{i,y} \qquad \forall i, y$$

Budgetary Constraints:

$$\sum_{y' \le y}\left[\sum_{ip}\left(cost_{ip} * NEWBUY_{ip,y'}\right) + \sum_{b}\left(UNDERBDGT_{b,y'} - OVERBDGT_{b,y'}\right)\right] = \sum_{y' \le y} budget_{y'} \qquad \forall i, y$$

$$\sum_{b>5\%} OVERBDGT_{b,y} \le \sum_{b>5\%} \left(break_{b} - break_{b-1}\right) * budget_{y} \qquad \forall y$$

$$OVERBDGT_{5\%,y} \le break_{5\%} * budget_{y} \qquad \forall y$$

Stock Level Constraints:

$$STOCK_{ip,y} \leq auth_{ip} + ADJAUTH_{ip,y} \qquad \forall ip, y$$

Persistence Constraint:

$$ABLE_{m,y} - ABLE_{m,y-1} + DNTICK_{m,y} - UPTICK_{m,y} = 0 \qquad \forall m, y$$

Initial Conditions:

$$STOCK_{i,inity} = initstock_i \qquad \forall i$$

$$ABLE_{m,inity} = 0 \qquad \forall m$$

$$NEWBUY_{i,inity} = 0 \qquad \forall i$$

Variable Bounds:

$$0 \leq NEWBUY_{ip,y} \leq \left(budget_y / cost_{i,p}\right), \text{ and integer} \qquad \forall ip, y$$

$$missmult_y - 1 \leq ABLE_{m,y} \leq missmult_y, \text{ and binary} \qquad \forall m, y$$

$$0 \leq STOCK_{i,y} \leq \max\left\{\left(maxmult * totaluse_i\right), \left(initstock_i\right)\right\}, \text{ and integer} \qquad \forall i, y$$

$$ISSUED_{i,y(i)} \geq 0 \qquad \forall i, y(i)$$

$$SUBITEM_{i,is(i),y(i)} \geq 0, \text{ and integer} \qquad \forall i, is(i), y$$

$$ADJAUTH_{i,y} \geq 0 \qquad \forall i, y$$

$$OVERBDGT_{b,y} \geq 0 \qquad \forall b, y$$

$$UNDERBDGT_{b,y} \geq 0 \qquad \forall b, y$$

$$DNTICK_{m,y} \geq 0 \qquad \forall m, y$$

$$UPTICK_{m,y} \geq 0 \qquad \forall m, y$$

The solution technique uses the General Algebraic Modeling System (GAMS) release 2.25 version 92 (Brooke et al., 1997) and the CPLEX solver, version 6.5 (ILOG, 2000). The mission ability calculation, or objective function, credits for any mission that can be fully equipped by the end of a year, but penalizes for any budgetary and/or mission persistence violations.

There are several constraint sets and important variable bounds implemented within the optimization model.

If a mission is considered available, then "Mission Loadout Constraints" ensure sufficient weapons and equipment for its loadout are also available, including the possibility that item substitutions may be allowed in given multiples.

At the end of each year, "Budgetary Constraints" make a cumulative accounting of spending over the entire planning horizon to date and compare it with the annual budget targets, and any cumulative violation over- or under-budget total is reckoned. The penalty for such violations in the objective function increases sharply with the violation, discouraging any but trivial violations.

Authorization levels and any adjustments made in previous years govern the total quantity of each item i, held in inventory in the "Stock Level Constraints".

If a mission ability changes year-to-year, a "Persistence Constraint" violation is recorded and is penalized in the objective function.

"Initial Conditions" specify unit stocks at the start of the planning, as well as any pre-committed new purchases or permitted stock level changes.

An upper bound on the new purchase variable, $NEWBUY_{ip,y}$, is induced by the entire annual budget.

Lower and upper bounds on the decision variable $ABLE_{m,y}$, restrict the number of each mission m that can be performed in year y.

The item inventory status variable $STOCK_{i,y}$ is bounded by the maximum of the total number of item i used in year y by *all* candidate missions, or its initial inventory.

All variables are non-negative, and some are restricted to binary, or integral values.

2. Optimal Solution Technique Output

The optimal solution technique recommends an annual "shopping list" for each year in the planning horizon, accounting for mission abilities as they are achieved. The total "mission ability years" is an effective gauge of our success. In addition, blemishes are reported, such as any cumulative over- or under-budget violations up through the end of each year, or violations of mission ability persistence. Finally, the solution technique reports the stock level for each of the items in JOS and any adjustments needed to the authorization level.

Despite the advantages of the optimal solution technique, it does have two major drawbacks: cost and complexity. GAMS, and the associated solver CPLEX are commercially available, but at around $6,000 per copy. Additionally, maintenance or development of the optimal solution technique requires a trained specialist.

IV. COMPARISON OF HEURISTIC AND OPTIMAL SOLUTION TECHNIQUES

The distinguishing differences between using the heuristic and the optimal solution techniques are the higher complexity and cost of the latter. If the heuristic can produce solutions close to the optimal solution technique, it is clearly preferable. Better, the heuristic is easily explained and understood.

A. TEST PROBLEM

The problem we use to validate the heuristic has a ten-year planning horizon, containing a variety of candidate SOF missions (see Appendix A). In FY00 we start with the current JOS inventory and a requirement to complete one of each of the SOF DA and SR missions. In FY03 we increase the mission requirement to two of each of the SOF missions, thus increasing our choices to 20 candidate missions. In FY06 and FY010 we once again increase the requirement by one, raising our candidates to 30 and 40 respectively.

In addition to increasing the number of candidate mission alternatives, we also schedule the introduction and retirement of equipment. In FY02 we introduce a mission loadout requirement for two high technology items. In FY07 we retire several pieces of equipment; up to this year, these are substitute items for preferred items.

B. TOTAL MISSION ABILITY ACHIEVEMENT

By the end of the 10-year planning horizon, the heuristic solution technique accumulates 220 mission ability years, and the optimal solution technique 229. Both reach

33 simultaneous missions by the end of FY10. The omniscient optimal solution technique slightly outperforms the myopic heuristic. However, in each year the heuristic is always within four missions of the optimal solution technique (see Figure 7).

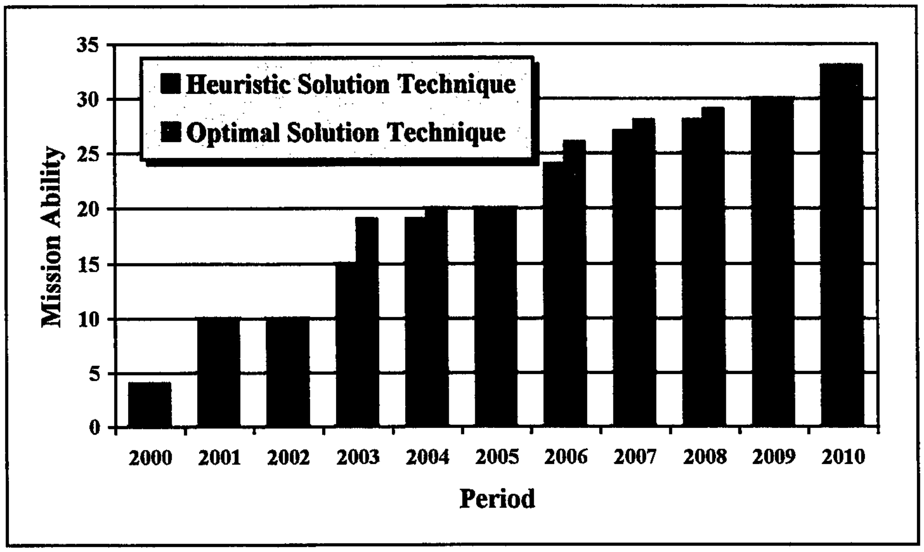

Figure 7. Planned Mission Ability of the JOS Inventory. By the end of a 10-year planning horizon, the heuristic and the optimal solution techniques both accumulate a total mission ability of 220 and 229 mission-years respectively. Year-by-year, the mission ability difference between the optimal solution technique and the heuristic is less significant, with both reaching the ability to complete 33 simultaneous missions in FY10. Each solution technique consistently increases mission ability, with the omniscient optimal solution technique slightly outperforming the myopic heuristic. Despite the myopic nature of the heuristic, it is always within four missions of the optimal solution technique.

The myopic heuristic lags the omniscient optimal solution technique because the heuristic does not look ahead to plan for future changes to the mission requirements or to the inventory. The heuristic does not purchase in the present year to anticipate far-future requirements. By FY03, the optimal solution technique has achieved a mission portfolio better than the heuristic. The optimal solution technique performs slightly better than the heuristic by purchasing items in the early years of the planning horizon to cover inventory changes in later years, such as the introduction of new technology, or the phasing out of

old technology. For example, the heuristic uses 46% of its FY08 budget to purchase 177 MBITR needed to fill the demand left by the retirement of the two SABER Handheld Radio Sets. Despite this, the heuristic is within one mission of the optimal solution technique in FY07.

Both tools increase in mission ability at about the same rate (see Figure 8). In FY01, both are able to complete all ten missions simultaneously. The optimal solution technique achieves the capability of completing each of the ten missions twice simultaneously in FY04, while the heuristic achieves this the following year. In FY09, both techniques reach the ability to complete each mission three times simultaneously. Finally, in FY10, both tools add one to each of the capabilities of three of the missions.

C. OVER- AND UNDER-BUDGET EXPENDITURES

Because purchases are discrete, neither tool can find the exact combination of purchases that exactly equals the annual budget. The heuristic performs slightly better than the optimal solution technique with respect to the budgetary constraints. The heuristic is always within 0.1% of the actual budget, and the optimal solution technique stays within 1.2% (this 1.2% occurred in FY00 where the optimal solution technique's over-expenditure was amplified by a small budget) (see Figure 10). Both tools stay close to budget. Neither technique exceeds $5,200 over- or under-budget in a single year, or $7,600 cumulatively over- or under-budget over the entire planning horizon (see Figure 9). Because both techniques are so close to budget, neither incurs any significant penalty for violation of the yearly budget constraints.

Heuristic (H) vs. Optimal (O) Solution Technique
Mission Ability by Mission and Year

		DA1	DA2	DA3	DA4	DA5	DA6	SR1	SR2	SR3	SR4
FY00	H				●			●	●		●
	O							●	●	●	●
FY01	H	●	●	●	●	●	●	●	●	●	●
	O	●	●	●	●	●	●	●	●	●	●
FY02	H	●	●	●	●	●	●	●	●	●	●
	O	●	●	●	●	●	●	●	●	●	●
FY03	H	●	●●	●	●	●	●	●●	●●	●●	●●
	O	●	●●	●●	●●	●●	●●	●●	●●	●●	●●
FY04	H	●	●●	●●	●●	●●	●●	●●	●●	●●	●●
	O	●●	●●	●●	●●	●●	●●	●●	●●	●●	●●
FY05	H	●●	●●	●●	●●	●●	●●	●●	●●	●●	●●
	O	●●	●●	●●	●●	●●	●●	●●	●●	●●	●●
FY06	H	●●●	●●	●●	●●	●●	●●	●●	●●●	●●●	●●●
	O	●●	●●	●●	●●●	●●●	●●	●●●	●●●	●●●	●●●
FY07	H	●●●	●●	●●	●●●	●●	●●●	●●●	●●●	●●●	●●●
	O	●●●	●●●	●●	●●●	●●●	●●	●●●	●●●	●●●	●●●
FY08	H	●●●	●●●	●●	●●●	●●	●●●	●●●	●●●	●●●	●●●
	O	●●●	●●●	●●●	●●●	●●●	●●	●●●	●●●	●●●	●●●
FY09	H	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
	O	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
FY10	H	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●●	●●●●	●●●●
	O	●●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●●	●●●	●●●●

Figure 8. Comparison between the Yearly Mission Ability of the Heuristic Solution Technique and Optimal Solution Technique. The objective of both techniques is to maximize the number of performable missions, or mission ability, each period, given the current inventory and new purchases. By the end of the planning horizon, both techniques are able to complete 33 simultaneous missions. Both achieve the ability to complete 10 missions simultaneously in FY01. The optimal solution technique is able to complete 20 missions simultaneously in FY04, and the heuristic solution technique follows a year later in FY05. Both techniques are capable of performing 30 missions simultaneously in FY09, and in FY10, both techniques augment three additional missions to four simultaneous loadouts.

Suppose we enforce the yearly budgets exactly. The total mission ability of JOS drops dramatically: the optimal solution technique from 229 to 174, with the final capability of completing only 19 missions in FY10.

Both techniques perform well, staying very close to the budgetary guidance.

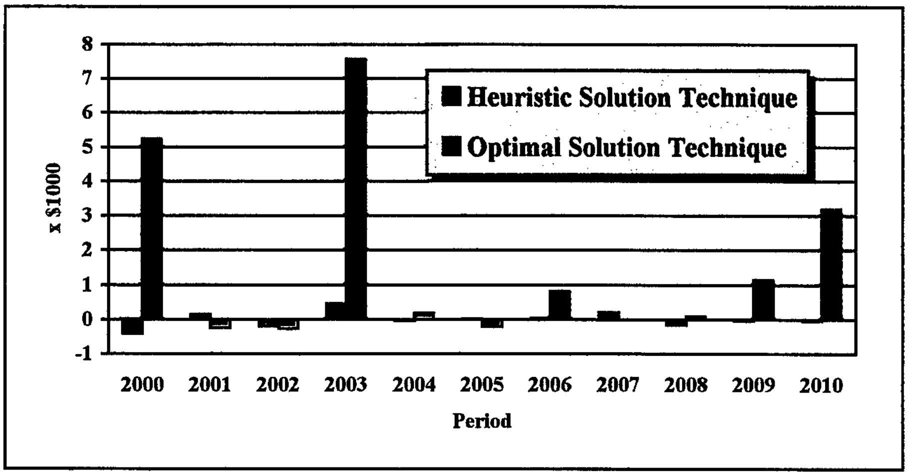

Figure 9. Cumulative Over- and Under-Budget Spending. Both tools stay close to the annual budget. The heuristic stays closer to the budget because it procures any item which will use any remaining funds in the budget. The optimal solution technique looks for the optimal mix of items that will satisfy not only current but also future needs, thus avoiding any extraneous expenditure. However, even with this omniscient policy, the maximum over-expenditure is $7,546.00 in FY03, which is only 0.3% of the FY03 budget.

D. PERSISTENT SOLUTIONS

Both tools are persistent in the retention of mission abilities from year-to-year. The only persistence violations that occur are the increases in mission ability.

E. YEARLY SHOPPING LIST

Our objective is an annual shopping list of items needed to maximize the mission ability of JOS. Both tools procure roughly the same equipment in the same quantity, with the only major difference being in the timing of the purchases (see Appendix B for the shopping lists). Because the heuristic also purchases additional items in order to buy out substitutes, some items appear on the heuristic shopping list and not the optimal solution techniques.

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V. HISTORIC CONTEXT FOR THE JOS HEURISTIC IN CAPITAL BUDGETING AND RESOURCE ALLOCATION LITERATURE

The military has applied a wide variety of capital budgeting models, ranging in size and scope. The preferred method for solving such problems is optimization. The large-scale optimization model PHOENIX (Brown et al. 1991), has suggested a shopping list to modernize the US Army helicopter fleet. Ihde (1995) chooses an optimal set of anti-armor weapons and their corresponding production schedules. Each of these models utilizes an elaborate optimization program to produce an optimal solution, PHOENIX for large unit prices, and Idhe for unit prices more in scale with our SO problem.

The US Army Training and Doctrine Command (TRADOC) used a variation of the Senju and Toyoda heuristic to suggest the best one-time combination of modernization plans that would maximize the warfighting benefits achieved. This heuristic capital allocation, developed by Dr. Mike Anderson at TRADOC Analysis Center, Fort Leavenworth, Kansas (Anderson, 6 June 2000), follows Senju and Toyoda by stating the cost of each candidate modernization action in terms of amount of resources required to satisfy the proposal ($use_{p,r}$), and the period budget to the amount of a limited resource available ($available_r$). This straightforward application of Senju and Toyoda consolidates all the periods of the multi-period planning horizon into one.

By contrast, we intentionally induce period-by-period myopia to accommodate bookkeeping over the periods of the planning horizon, and to recognize and reward the early achievement of mission abilities. Our problem is time-dynamic, rather than time-aggregated.

Donahue (1992) proposes an optimization model to replace the TRADOC heuristic, justifying the effort reasonably enough by the sheer magnitude of the $120 billion investment being planned over fifteen years.

So, formal optimization has been proposed for multi-billion dollar, multi-period capital investment programs.

We propose our modest heuristic for planning investments of merely a few million dollars. We cannot assume that our relatively small-scale plans warrant elegant technology or analysis, or hiring new operations research staff not now in residence.

Best of all, we now have ubiquitous spreadsheet tools that enable our proposed heuristic decision support tool to be delivered to a desktop with minimal investment, to be used with ease, and to be maintained and enhanced without mathematical extravagance.

VI. FUTURE AREAS OF STUDY AND CONCLUSIONS

A. FUTURE AREAS OF STUDY

Direct Action and Special Reconnaissance missions have been used as examples here, but there are more types of missions. The heuristic needs to be enhanced to accommodate as many forecastable missions as possible.

Although the heuristic solution technique uses EXCEL^{tm}, there is no graphical user interface (GUI). The development of a GUI would allow the user to simply input missions and their requirements, any substitutes, new technology, future inventory changes, and the yearly budgets, and the solution technique would automatically suggest the mission ability for each year, and a shopping list for every year in the horizon.

JOS may need a companion tool to use historical demands and expert judgment to suggest candidate future missions and loadouts. The Analytical Heirarchy Process (AHP) (Saaty, 1990) appeals here to deal with conflicting expert opinion among SO leaders from the various services. AHP can quantify the relative importance of each candidate mission by asking various service experts to rank the importance of the missions. AHP then specifies a maximally consistent ranking among these presumably conflicting expert opinions.

B. CONCLUSIONS

If the heuristic solution technique were omniscient, it might be expected to suggest plans even closer to those of the optimal solution technique. However, myopia may be one of the heuristic's attractions.

Omniscient models have a well-earned reputation for suggesting drastic near-term actions in anticipation of long-term conditions --- conditions that may only be forecast with uncertainty. For instance, Brown et al. (1997) report that the Kellogg Corporation prefers a myopic model to plan an 18-month production horizon, because the omniscient model, even though it is able to predict and plan for future spikes in demand, creates "nervousness" in its results. When far-term demand *forecasts* change, the omniscient model makes dramatic shifts in the production plan to account for these changes.

Changes, even small ones, to our optimal, omniscient optimization solution technique's "known" future budget, mission numbers or types, item service life, etc., can also produce drastic near-term vacillation. Because the myopic heuristic only plans for the current year, its behavior is much easier to predict and understand. As we have shown, myopia comes at a modest price in overall solution quality.

We conclude that the heuristic is a simple and easily understood management tool for JOS procurement funding, quickly producing near-optimal shopping list for every year in a multi-year planning horizon.

APPENDIX A. MISSION LOADOUTS

MISSION LOADOUTS	Number of each item required to completely loadout a mission										NOTES
JOS LINE ITEMS	DA1	DA2	DA3	DA4	DA5	DA6	SR1	SR2	SR3	SR4	
SR-25 Sniper Rifle	3	2	2	2	2	2	2	2	2	2	
Barrett 50 CAL Sniper Rifle	2	2	2	1	2	2	2	1	1	1	
300 WIN MAG Sniper Rifle	3	1	2		2	2	2	1	1	1	
MP5A3 Submachine Gun											A
MP5A5 Submachine Gun	7	6	5	8	5	2	7	7	12	12	
MP5SD3 Submachine Gun	4	2	2	2	6	4	2	2	2	2	
PVS7B Night Vision Goggles											B
PVS7D Night Vision Goggles	11	8	8	9	9	8	8	8	7	8	
AN/PVS-15 Night Vision Binoculars	2	2	2	2	2	2	2	2	2	2	
M938XR Intensifier Tube	6	3	5	4	4	4	4	4	4	5	
Stabilized Binoculars	4	3	5	3	4	4	3	3	3	3	C
IL-7 IR Illuminator											D
AN/PEQ-2 IR Illuminator	7	5	4	7	6	5	6	5	5	7	
AN/PEQ-1 Laser Target Designator											E
AN/PAS-13 Laser Night Sight	2	3	2	2	3	3	2	2	2	2	
LPL-30 IR Laser, Long Range Pointer	5	3	3	4	3	3	5	5	5	5	
GCP-1B Ground Commander's IR Pointer											F
GCP-2A Ground Commander's IR Pointer	2	2	2	2	2	2	2	2	2	2	
N/CROS MKII Laser Range/Compass Binocular	2	2	2	2	2	2	2	1	1	1	
AN/PVS-6 Mini Eyesafe Laser IR Observation Set	2	2	2	2	2	2	2	1	1	1	
100-500 MM Camera Zoom Lens	2	2	2	2	1	2	2	2	2	2	
3rd Gen or Higher Night Vision Pocketscope	8	10	9	9	8	12	5	4	4	4	G
Bushnell Spotting Scope	2	3	3	3	2	3	3	3	3	3	
KN-200F Optical Sight											H
KN-250 Night Vision Sight											I
Improved Night and Day Scope	6	4	6	5	6	6	6	8	8	8	
MAG 600 Thermal Imaging Sight	3	2	3	3	3	2	5	5	5	5	
AN/PAS-19 Thermal Imaging Sight											J
AN/PAS-20 Thermal Imaging Sight											K
Tactical Surveillance System	3	3	3	2	3	3	2	2	2	2	
AN/PAS-18 Stinger Night Sight	2	2	2	2	2	2	2		1		
M995 Night Vision Sight	8	5	6	6	4	4	6	7	7	7	
DMSE-109-1 SATCOM Antenna	3	2	2	3	2	2	4	4	4	4	
AV2040-3 SATCOM Antenna											L
AV2055-3 Improved Lightweight Satellite Antenna											M
C-130 Hatchmount SATCOM Antenna	1	1	1	1	1	1	1	1	1	1	
C-141 Hatchmount SATCOM Antenna	1	1	1	1	1	1	1	1	1	1	
SMP-1000 Micro Ponder	3	3	3	2	2	3	3	2	2	2	
AN/CSZ-1A Sunburst Processor	2	2	2	2	2	2	2	2	2	2	
MFAX 5000 (Non-Tempest)											N
MFAX 5000 (Tempest)	2	2	2	2	2	2	2	2	2	2	
INMARSAT "B"	2	2	2	2	2	2	2	2	2	2	
AN/PRC-117D Radio Set											O
AN/PRC-113 (V)3 Radio Set	3	3	2	3	3	3	3	2	3	3	
AN/PRC-138 (V)2 Radio Set	2	3	2	2	3	3	2	2	2	2	
SABER I Handheld Radio Set											P
SABER II Handheld Radio Set											Q
SABER Microphone keypad	6	4	4	6	4	4	4	2	2	2	
SABER Vehicle Adapter Kit	2	3	3	3	3	3	2	1	1	1	
SABER 6-Unit Charger	2	2	2	2	2	2	2	2	2	2	
SABER Single-Unit Charger	1	1	1	1	1	1	1	1	1	1	
SABER Headset	9	8	8	9	8	6	9	10	10	10	
SABER Vehicle Antenna Mount	2	2	2	2	2	2	2	1	1	1	

SABER Repeater with Security Kit	2	2	2	2	2	2	2	2	2	2	
MST-20 SATCOM Radio											R
MBITR	10	10	10	10	10	10	10	11	11	11	
MBMMR	4	3	3	5	3	3	4	6	6	6	
32X72, 30 Ply Breacher Blanket											S
Breacher Blanket with Case	2	2	2	2	2	2					
AN/PPN-19 RADAR Beacon											T
F470 Zodiac Inflatable Boat	2	2	2	2	2	2	2	2	2	2	
TAC-100 Diver Navigation Board	3	3	3	3	3	5	3	2	2	2	
GPS 1000 M5 MDL 21002 Navigation Set											U
AN/PSN-11 (V)1 GPS Receiver	4	4	4	4	4	4	5	4	4	4	
XLG Zinner Vest											V
LG Zinner Vest											W
MED-LG Zinner Vest											X
MED Zinner Vest											Y
XLG Ranger Body Armor	2	2	2	2	2	2	2	2	2	2	
LG Ranger Body Armor	8	8	8	8	8	8	8	8	8	8	
MED Ranger Body Armor	2	2	2	2	2	2	2	2	2	2	
GENTEX Communications Helmet	11	11	11	11	11	11	11	10	10	10	
5KW Portable Generator											Z
10KW Portable Generator											AA
30KW Portable Generator											AB
60KW Portable Generator	2	2	2	2	2	2	1	1	1	1	
100KW Portable Generator											AC
15KW Power Distribution Panel											AD
30KW Power Distribution Panel											AE
60KW Power Distribution Panel	2	2	2	2	2	2	1	2	2	2	
100KW Power Distribution Panel											AF
MDL 51 Environmental Control Unit	1	1	1	1	1	1		1		1	
Field Shower Unit	1	1	1	1	1	1			1		
Fuel Powered Light Set											AG
MDL FS100 Electric Light Set	1	1	1	1	1	1					
800 PSI Pressure Washer	1	1	1	1	1	1					
MDL 150 Water Filtration Unit											AH
MDL 6000 Water Filtration Unit	3	3	3	3	3	3	3	3	3	3	
Solar Water Filtration System								1		1	
MDL SP2 Water Purification Unit	2	2	2	2	2	2	2	2	2	2	
LS/RO-1500 Water Desalination Unit											AI
Tent 32X20											AJ
Tent with Liner		1						1	1	1	
Maintenance Shelter		1									

Notes:

A. Item used as substitute for MP5A5 and MP5SD3 Submachine Guns.

B. Item used as substitute for PVS7D Night Vision Goggles and AN/PVS-15 Night Vision Binoculars. **Item retired in FY07.**

C. **New Technology introduced in FY02.**

D. Item not required for any of the specified missions.

E. Item used as substitute for AN/PAS-13 Laser Night Sight.

F. Item used as substitute for AN/PEQ-2 IR Illuminator, and GCP-2A Ground Commander's IR Pointer.

G. **New Technology introduced in FY02.**

H-I. Items used as substitutes for Improved Night and Day Scope.

J-K. Items used as substitutes for MAG 600 Thermal Imaging Sight.

L-M. Items used as substitutes for DMSE-109 SATCOM Antenna.

N. Item not required for any of the specified missions.

O. Item used as substitute for MBMMR.
P-Q. Items used as substitutes for MBITR. **Items retired in FY07.**
R. Item used as substitute for MBMMR.
S. Item used as substitute for Breacher Blanket with Case.
T. Item used as substitute for SMP-1000 Micro Ponder. **Item retired in FY07.**
U. Item used as substitute for AN/PSN-11 (V)1 GPS Receiver.
V-Y. Items used as substitutes for varying sizes of Ranger Body Armor.
Z-AC. Items used as substitutes for 60KW Portable Generator.
AD-AF. Items used as substitutes for 60KW Power Distribution Panel.
AG. Item used as substitute for MDL FS100 Electric Light Set.
AH. Item used as substitute for MDL 6000 Water Filtration Unit.
AI. Item not required for any of the specified missions.
AJ. Item used as a substitute for Tent with Liner.

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APPENDIX B. HEURISTIC VS. OPTIMAL SOLUTION TECHNIQUE YEARLY PURCHASES

MYOPIC HEURISTIC SOLUTION TECHNIQUE

JOS LINE ITEMS	Number of each Line Item Purchased in Fiscal Year										
	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
SR-25 Sniper Rifle											
Barrett 50 CAL Sniper Rifle											
300 WIN MAG Sniper Rifle				6	9		6	4	1	4	3
MP5A3 Submachine Gun											
MP5A5 Submachine Gun											
MP5SD3 Submachine Gun		16				14				16	27
PVS7B Night Vision Goggles											
PVS7D Night Vision Goggles		45	39			39			117	12	23
AN/PVS-15 Night Vision Binoculars									7	2	6
M938XR Intensifier Tube										8	13
Stabilized Binoculars			35	15	20		13	12	5	5	9
IL-7 IR Illuminator											
AN/PEQ-2 IR Illuminator		16	21		17	19	12	29	8	8	25
AN/PEQ-1 Laser Target Designator											
AN/PAS-13 Laser Night Sight						6				16	2
LPL-30 IR Laser, Long Range Pointer				11	10		9	8	5	2	7
GCP-1B Ground Commander's IR Pointer											
GCP-2A Ground Commander's IR Pointer						1				10	2
N/CROS MKII Laser Range/Compass Binocular		4	6			12				15	
AN/PVS-6 Mini Eyesafe Laser IR Observation Set											
100-500 MM Camera Zoom Lens					4		9	7	4	2	7
3rd Gen or Higher Night Vision Pocketscope			73	31	42		20	31	14	8	12
Bushnell Spotting Scope											
KN-200F Optical Sight											
KN-250 Night Vision Sight											
Improved Night and Day Scope		25	30			36				27	
MAG 600 Thermal Imaging Sight		2	2			19				1	7
AN/PAS-19 Thermal Imaging Sight											
AN/PAS-20 Thermal Imaging Sight											
Tactical Surveillance System	6	17	6	6	12	1	9	9	4	3	6
AN/PAS-18 Stinger Night Sight					7		3	7	3	2	1
M995 Night Vision Sight				26	20	6	29	19	3	9	21
DMSE-109-1 SATCOM Antenna		2	3			15				4	
AV2040-3 SATCOM Antenna											
AV2055-3 Improved Lightweight Satellite Antenna											
C-130 Hatchmount SATCOM Antenna						1	4	4		2	3
C-141 Hatchmount SATCOM Antenna		4		6	3	1	4	4		2	3
SMP-1000 Micro Ponder		10	8			15			37	5	6
AN/CSZ-1A Sunburst Processor		10		12	6	2	8	7	1	4	6
MFAX 5000 (Non-Tempest)											
MFAX 5000 (Tempest)				7	8	2	8	7	3	2	6
INMARSAT "B"				12	6	2	8	7	1	4	6
AN/PRC-117D Radio Set											
AN/PRC-113 (V)3 Radio Set											
AN/PRC-138 (V)2 Radio Set											
SABER I Handheld Radio Set											
SABER II Handheld Radio Set											
SABER Microphone keypad		20		20	18	6	12	14	4	8	7
SABER Vehicle Adapter Kit						2	5	9	2	6	3
SABER 6-Unit Charger		4	5	3	9	5	5	7	1	4	8
SABER Single-Unit Charger											
SABER Headset	1	44		56	22	9	39	25	8	16	30
SABER Vehicle Antenna Mount								1		4	3

SABER Repeater with Security Kit	4	12		12	6	2	8	7	1	4	6
MST-20 SATCOM Radio											
MBITR		41	31			40			177	20	33
MBMMR		24	18			10					
32X72, 30 Ply Breacher Blanket											
Breacher Blanket with Case											
AN/PPN-19 RADAR Beacon											
F470 Zodiac Inflatable Boat				12	6	2	8	7	1	4	6
TAC-100 Diver Navigation Board				2	11	3	9	13	1	6	6
GPS 1000 M5 MDL 21002 Navigation Set											
AN/PSN-11 (V)1 GPS Receiver						1					
XLG Zinner Vest											
LG Zinner Vest											
MED-LG Zinner Vest											
MED Zinner Vest											
XLG Ranger Body Armor											
LG Ranger Body Armor											
MED Ranger Body Armor											
GENTEX Communications Helmet	29	58		60	30	10	40	30	10	20	30
5KW Portable Generator											
10KW Portable Generator											
30KW Portable Generator											
60KW Portable Generator					4	5	2	6	1	4	3
100KW Portable Generator											
15KW Power Distribution Panel											
30KW Power Distribution Panel											
60KW Power Distribution Panel		6	8			14					2
100KW Power Distribution Panel											
MDL 51 Environmental Control Unit							3	3		2	2
Field Shower Unit		1		3	3	1	2	3		2	1
Fuel Powered Light Set											
MDL FS100 Electric Light Set						1		3		2	
800 PSI Pressure Washer		4		2	3	1	1	3		2	
MDL 150 Water Filtration Unit											
MDL 6000 Water Filtration Unit	3	18	5	13	9	3	12	9	3	6	9
Solar Water Filtration System							2				2
MDL SP2 Water Purification Unit				2	6	2	8	7	1	4	6
LS/RO-1500 Water Desalination Unit											
Tent 32X20											
Tent with Liner											
Maintenance Shelter											

OPTIMAL SOLUTION TECHNIQUE

JOS LINE ITEMS	Number of each Line Item Purchased in Fiscal Year										
	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
SR-25 Sniper Rifle											
Barrett 50 CAL Sniper Rifle											
300 WIN MAG Sniper Rifle		11		1	4	7		3	3	5	1
MP5A3 Submachine Gun											
MP5A5 Submachine Gun		23			55	4		18		22	5
MP5SD3 Submachine Gun											
PVS7B Night Vision Goggles											
PVS7D Night Vision Goggles		55	2		12	5	49	14	107	32	3
AN/PVS-15 Night Vision Binoculars									8	6	2
M938XR Intensifier Tube									5	4	14
Stabilized Binoculars		1	65		14	11		5	5	5	10
IL-7 IR Illuminator								16			
AN/PEQ-2 IR Illuminator						2			6	8	24
AN/PEQ-1 Laser Target Designator											
AN/PAS-13 Laser Night Sight										2	7
LPL-30 IR Laser, Long Range Pointer		19		1	9	4		8		6	2
GCP-1B Ground Commander's IR Pointer											
GCP-2A Ground Commander's IR Pointer											
N/CROS MKII Laser Range/Compass Binocular											
AN/PVS-6 Mini Eyesafe Laser IR Observation Set											
100-500 MM Camera Zoom Lens		2			2	11		6		2	6
3rd Gen or Higher Night Vision Pocketscope		87	51		45	1	1	35		17	
Bushnell Spotting Scope											
KN-200F Optical Sight											
KN-250 Night Vision Sight											
Improved Night and Day Scope		9	3	7	8	6	36	7	6	9	19
MAG 600 Thermal Imaging Sight					6	3		5		21	1
AN/PAS-19 Thermal Imaging Sight											
AN/PAS-20 Thermal Imaging Sight											
Tactical Surveillance System	6	18	1	21	3	1	13	6	2	3	7
AN/PAS-18 Stinger Night Sight		1	4		3	6	1	5		3	2
M995 Night Vision Sight		1	39		9	1	39	15		24	2
DMSE-109-1 SATCOM Antenna											
AV2040-3 SATCOM Antenna											
AV2055-3 Improved Lightweight Satellite Antenna											
C-130 Hatchmount SATCOM Antenna					2	3	3	2		2	3
C-141 Hatchmount SATCOM Antenna		4	1	8	2	4	2	2	1	1	3
SMP-1000 Micro Ponder		7	2	2	4	14		4	39	4	6
AN/CSZ-1A Sunburst Processor		10	1	17	14		1	3	3	6	2
MFAX 5000 (Non-Tempest)											
MFAX 5000 (Tempest)		10	2	1	3	10	1	6		2	7
INMARSAT "B"		1	17		6	9		4	2	6	2
AN/PRC-117D Radio Set											
AN/PRC-113 (V)3 Radio Set											
AN/PRC-138 (V)2 Radio Set											
SABER I Handheld Radio Set											
SABER II Handheld Radio Set											
SABER Microphone keypad		52			6	20		14		4	10
SABER Vehicle Adapter Kit					8	10			3	8	1
SABER 6-Unit Charger		15	3	2	9	6		3	2	2	7
SABER Single-Unit Charger											
SABER Headset		122			9	12	44	25	1	5	29
SABER Vehicle Antenna Mount								3	1	1	5
SABER Repeater with Security Kit	5	12	1	16	13		1	4	3	2	6

MST-20 SATCOM Radio											
MBITR					7		67	15	211	12	29
MBMMR					1	37		16		8	17
32X72, 30 Ply Breacher Blanket											
Breacher Blanket with Case											
AN/PPN-19 RADAR Beacon											
F470 Zodiac Inflatable Boat			17	1	13		1	4	3	6	2
TAC-100 Diver Navigation Board		13			3	13	2	11		3	7
GPS 1000 M5 MDL 21002 Navigation Set											
AN/PSN-11 (V)1 GPS Receiver											
XLG Zinner Vest											
LG Zinner Vest											
MED-LG Zinner Vest											
MED Zinner Vest											
XLG Ranger Body Armor											
LG Ranger Body Armor											
MED Ranger Body Armor											
GENTEX Communications Helmet	24	64	4	82	67		3	20	10	39	1
5KW Portable Generator											
10KW Portable Generator											
30KW Portable Generator											
60KW Portable Generator			3	1	11	1	1	3		5	1
100KW Portable Generator											
15KW Power Distribution Panel											
30KW Power Distribution Panel											
60KW Power Distribution Panel		13		3	3	10		6		3	6
100KW Power Distribution Panel											
MDL 51 Environmental Control Unit						5		2		1	3
Field Shower Unit		1	5	1	2	1	2	1	2		1
Fuel Powered Light Set											
MDL FS100 Electric Light Set					2			3		1	1
800 PSI Pressure Washer		6		3	1	2		2	2		1
MDL 150 Water Filtration Unit											
MDL 6000 Water Filtration Unit	3	19	12	14	4	12	7	7	1	3	10
Solar Water Filtration System					1	1				1	1
MDL SP2 Water Purification Unit		5	1	2	3	5	6	6		3	6
LS/RO-1500 Water Desalination Unit											
Tent 32X20											
Tent with Liner											
Maintenance Shelter											

LIST OF REFERENCES

Adams, T. (1998). US Special Operations Forces in Action: The Challenge of Unconventional Warfare. Portland: Frank Cass.

Anderson, M. (6 June 2000). Phone conversation between Dr. Michael Anderson, US Army TRADOC's capital allocation heuristic developer, and author.

Brooke, A., Kendrick, D., Meeraus, A., Raman R. (1997). GAMS: A User's Guide. Washington D.C.: The Scientific Press.

Brown, G., Clemence, R., Teufert, W., Wood, R. (1991). "An Optimization Model for Modernizing the Army's Helicopter Fleet". Interfaces, Vol. 12, No. 4, pp. 39-52.

Brown, G., Dell, R., Wood, R. (1997). "Optimization and Persistence". Interfaces, Vol. 27, No. 5, pp. 15-37.

Devore, J. (1995). Probability and Statistics for Engineering and the Sciences, (4th ed.). Pacific Grove: Brooks and Cole.

Donahue, S. (1992). "An Optimization Model for Army Planning and Programming". Masters Thesis in Operations Research, Naval Postgraduate School.

Fahringer, P. (1999). "Joint Operational Stocks Inventory Purchasing Prioritization Methodology". Masters Thesis in Operations Research, Naval Postgraduate School.

Henrickson, J., Senior JOS Manager. Email message of 10 March 2000.

Henrickson, J., Senior JOS Manager. Email message of 30 March 2000.

Henrickson, J., Senior JOS Manager. Email message of 21 April 2000.

Ihde, A. (1995). "An Optimization Model for Anti-Armor Weapon Systems Acquisition". Masters Thesis in Operations Research, Naval Postgraduate School.

ILOG, 1999, "CPLEX 6.5", [http://www.cplex.com], June.

Saaty, T. (1990). "How to make a decision: The Analytic Hierarchy Process". European Journal Of Operational Research, Vol. 48, pp. 9-26.

Senju, S., Toyoda, Y. (1968). "An Approach to Linear Programming with 0-1 Variables". Management Science, Vol. 15 No. 4, pp. B196-207.

Sherbrook, C. (1992) Optimal Inventory Modeling of Systems: Multi-Echelon Techniques. New York: John Wiley and Sons.

SOFSA (1999). "Joint Operational Stocks Catalog". Tampa: United States Special Operations Command.

Tisak, F., CDR, USN, Director of JOS Programs. Email message of 8 September 1999.

USSOCOM (1996). "United States Special Operations Forces 1996 Posture Statement". Tampa: United States Special Operations Command.

USSOCOM PUB 1 (1996). "Special Operations in Peace and War". Tampa: United States Special Operations Command.

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